CONNECTING K-12 SCHOOLS TO THE INFORMATION SUPERHIGHWAY

McKinsey & Company

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PREFACE

This report was developed by McKinsey & Company, Inc. for the
National Information Infrastructure Advisory Council (NIIAC). Many
individuals from educational organizations, industry, and federal, state
and local governments lent their expertise to this effort. While their
contributions have been invaluable, the report does not necessarily
reflect the views of any one contributor, the NIIAC, or its members.
Comments and questions concerning this work should be directed to
Michael Nevens, McKinsey and Company, Inc., 630 Hansen Way, Palo Alto,
California 94304; or to Margot Singer, McKinsey and Company, Inc.,
55 East 52nd Street, New York, New York 10022.

TABLE OF CONTENTS

The NII offers access to information, services, and people

The NII includes the Internet and other public and private networks accessible through computers, video equipment, or telephones. Collectively, these networks offer schools a wide range of information resources and services, including up-to-the-minute news reports, electronic libraries of government documents, electronic bulletin boards for debate of educational issues, multimedia "edutainment" products, on-line encyclopedias, and National Geographic's Kids Network.

Just as important, the information superhighway can connect students to a broad spectrum of human resources: teachers at other schools (including colleges): experts from museums, libraries, archives, and research institutes; and other students from around the world. Parents and other community members can become more involved in the educational process, as well, by dialing into the local school's network from home computers, from equipment made accessible through local libraries and community centers, or at the school itself if it provides after-hours access. The connection to the NII greatly expands the information resources available to students and teachers, and creates new channels for communication.

To illustrate: a typical morning at a middle school connected to the information superhighway might begin as one group of students arrives early to update the school's home page on the World Wide Web. This home page signals to other schools that also have electronic access to the Web that they have a sister school here whose students and teachers are interested in exchanging ideas about world events and other educational topics. At the same time, another group of early arrivals works with the vice principal to prepare the morning broadcast. Each school day formally starts with a live television presentation about the day's events; these presentations are written, directed, and produced by rotating teams of students and broadcast internally to all the classrooms. In the quiet minutes before this broadcast airs and classes start, a young language teacher is using his desktop computer to access an electronic bulletin board to see how language teachers from schools across the state have responded to his question about the best ways for explaining prepositions. Meantime, the principal is reviewing the electronic mail that parents sent her the evening before, prior to sending voice mail to all her teachers suggesting a schedule for the upcoming parent-teacher "open house."

Later in the morning, in a first-period modern history class, the same video technology that carried the local morning broadcast now enables this class to tour the Smithsonian's aerospace museum. In the classroom next door, the subject is anthropology. Students are grouped in teams of 3 and 4 around the classroom's computers, engrossed in a computer simulation that allows them to play the role of archaeologists on-site in Egypt, exploring ancient Egyptian culture as revealed

in its artifacts. In a classroom down the hall, each individual student is working math problems pitched at exactly the pace and level of difficulty appropriate for him or her, and getting immediate feedback on the answers, thanks to interactive software. At the same time, students in a writing class are drafting an essay assignment on their computers and employing electronic mail to get rapid feedback on their work from their peers....

Potential benefits of connecting are significant

None of the above is science fiction. These kinds of activities are taking place in innovative schools around the nation right now. And the early evidence from these schools suggests that in addition to exciting and engaging students, connection to the information superhighway can support important educational goals. At a minimum, connectivity promotes the computer literacy and networking/information skills that are prerequisite to an increasing number of jobs. By the year 2000, as much as 60% of American jobs may require such technology skills. In addition, by providing easier, faster, and more efficient access to a wide array of courseware, connectivity supports and enhances computer-assisted instruction, which has been proven effective in helping students master traditional academic subjects such as mathematics, science, and writing.

Many schools have experienced significant improvements in student performance after introducing computer-assisted instruction. For example, the Carrollton City School District in Georgia established a computer lab, among other changes, to reduce the failure rate in 9th grade algebra from 38% to 3%. In New Jersey, the Christopher Columbus Middle School saw student performance rise from well below to above state averages on standardized tests in reading, language arts, and math after the school implemented reforms that included extensive use of networked computers. The academic literature confirms technology's role in these improvements: a review of 254 controlled studies concluded that appropriate use of computers in the classroom reduces the time needed to master certain types of knowledge by as much as 30%. Put another way, in three school years, students benefiting from computer-assisted instruction can learn almost a full year's worth of material more than students who do not have access to the technology.

Furthermore, case studies suggest that when technology is integrated into the curriculum, it can support new teaching methods that emphasize critical thinking and investigative skills. For example, researchers have found that among students in California's Hueneme School District, average critical thinking abilities increased from the fortieth percentile to the eightieth percentile over the 12 years that the district has been integrating educational technology, including computers and electronic networks, into its classrooms.

Many options for connecting are available today—and affordable

While the coming years will see important technological advances such as wider availability of broadband networks—with their greater speed. capacity, and transmission quality—the basic technology needed for connecting schools to the information superhighway already exists today. However, connecting requires more than just the external connection from a school to the NII. It also requires a local area network at the school to link the equipment: computers, video equipment, and other hardware; electronic content in the form of multimedia courseware, educational video programs, and on-line services; professional development programs for teachers and other school professionals; and ongoing technical support.

To date, few public K-12 schools have assembled all the required elements of technology infrastructure. For example, while on average there are 14 multimedia-capable computers per K-12 school, distribution of these computers is highly uneven across schools. Some schools have many, others few. And while up to 50% of schools have already installed local area networks, less than 10% of these networks connect computers in all classrooms; most just connect administrative computers or a few classrooms. Similarly, almost all schools have telephone lines, but they are primarily used for administrative purposes—only 12% of classrooms have telephones.

There are many possible approaches to putting all these elements of technology infrastructure into place so that public K-12 schools can successfully connect to the NII. To provide a framework for considering the wide range of options for deploying the technology infrastructure, this report describes a series of deployment models that assume different timeframes (i.e., deployment to all public K-12 schools by the year 2000 versus by 2005) and different levels of technology infrastructure (e.g., connecting all classrooms to the NII versus connecting one multimedia lab per school). These models were chosen because they represent the prototypical technology choices that schools are actually making, and because they illustrate the key economic breakpoints among different levels of technology infrastructure—that is, the step functions in cost. The models focus on connecting to the information superhighway via networked computers. In addition, the report describes the costs of providing public K-12 schools with interactive video equipment, classroom telephones, and voicemail.

The costs associated with the computer-based models illustrate the size of the funding challenge. For example, connecting a computer lab with 25 multimedia-capable computers to the NII in every public K-12 school by the year 2000 would consume 1.5% of the currently projected education budget for 2000 (which would be the peak year of expenditures, assuming phased deployment over 5 years). The cost

of connecting every classroom in every public K-12 school by 2005 would represent 3.9% of the projected 2005 education budget (again, the year of maximum expenditures, assuming phased deployment over 10 years). Adding telephones, voice mail, and business quality video to the classroom model would require an additional 0.4% of the education budget.

Using today's spending as a benchmark, schools are not that far from the Lab model: schools currently spend 1.3% of the public K-12 education budget on similar technology. However, while school spending is close to the Lab model on average, the 1.3% figure include schools that spend more, and are consequently well down the road of technology deployment, and those that spend less and would have to begin nearly from scratch.

The models include both initial and ongoing costs for deployment. They include all investments needed to buy, install, operate, and maintain the equipment, as well as the costs of technical support staff and professional development for teachers. Not surprisingly, in all models purchasing and installing hardware constitutes the largest initial cost. But funding for substantial ongoing maintenance and support is also essential for successful deployment. During the period of deployment itself, professional development for teachers is the largest of these ongoing costs. By contrast, the actual costs of connection (e.g., Internet access, telephone bills) represent a relatively small part of overall expenditures.

Three challenges must be addressed

Once a school or district has set goals for infrastructure deployment, the pace of progress will depend primarily on the availability of funding, adequate development opportunities for teachers and other school professionals, and appropriate courseware. Each of these factors is critical for successfully connecting schools to the NII.

While the **funding** challenge in aggregate sounds reasonable, it must be noted that numerous pressures are squeezing education budgets at the national, state, and local levels. The funding picture is further complicated by the fact that educational technology is unevenly distributed across public K-12 schools. As mentioned above, some schools have already established an integral role for computers, video, and networks in their curricula. Many have experimented with the technology in a limited way. Others have yet to launch—or identify funding for—their first experiments.

It should nonetheless be possible to meet the funding challenge through a combination of cost reduction, reprogramming existing funds, and additional initiatives from the public and private sectors. In the area of cost reduction, for example, steps such as bulk purchasing taken

at the state or national level would reduce costs further than a typical district could on its own. In addition, certain categories of the school budget bear some relation to spending on technology infrastructure and thus might be reprogrammed to support connecting to the NII. For instance, a portion of the textbook budget might be shifted to acquiring on-line instructional materials. Finally, innovative schools across the country have secured funding through partnerships with corporations and community organizations.

Providing adequate **development opportunities for teachers and other school professionals** is the second critical factor for successful deployment. Teachers play the pivotal role in integrating the technology into the curriculum and facilitating its day-to-day use. But nearly 50% of today's teachers have had little or no computer experience, much less the training and confidence they need to fully integrate networked computers into their classroom teaching. The educational system currently offers little incentive to motivate teachers to build and apply technology skills. Incentives will need to be created and state certification requirements, teacher college curricula, and in-service training programs will need to be revamped to address technology skills. Providing development opportunities for other school professionals is also essential. School librarians, media specialists, and administrators often make decisions about technology purchases and advise teachers on technology use.

Finally, the value of the hardware and the network connections depends heavily on the quality of the educational materials they deliver. Meeting the diverse curriculum needs of all public K-12 schools will require a broad assortment of high-quality **courseware**. Currently, production of such courseware is limited because the market for such products is still relatively small. Widespread commitment to connecting the public K-12 schools to the information superhighway would accelerate growth of this market, which in turn would accelerate production of high-quality courseware. In addition, slow and cumbersome public school budgeting and procurement processes could be streamlined to speed up adoption of new courseware and make it easier for courseware developers to enter the public school market.

Connecting all public K-12 schools will take time— and leadership

Successfully connecting America's public K-12 schools to the NII involves coordinating several elements. Each school or district will need to make the commitment, and to make decisions about how much technology to deploy (connect one lab? every classroom? every desktop?) and how fast (establish lab-level connection by 2000? build out to the classroom level by 2005?). In making these decisions, the school or district will also need to identify adequate funding both for

installing the technology infrastructure and for supporting it going forward. Funds may come from multiple public and private sector sources; tapping this range of resources will often require both diligence and creativity. To make sure that the technology—once funded—is applied effectively in the classroom, teachers will need the opportunity, incentive, and support to experiment with it, master it, and learn to adopt and adapt it as a basic teaching tool. Finally, as more schools make commitments to connectivity and acquire funding, and as more teachers become excited about teaching with the NII, the demand for courseware will grow. In turn, this will stimulate development of more and better courseware for teachers to choose and adapt for their classrooms.

These elements will have to be addressed in parallel and the effort needs to begin now, because bringing the elements together will take time. It will require the sustained efforts and contributions of leaders at all levels—school, district, community, state, and federal. In each school and district, it will be necessary for local leaders to communicate a compelling vision, set clear goals, and generate enthusiasm for connectivity.

The deployment process has to be "bottom-up" by nature, since without the commitment of teachers, principals, school boards, parents, and other community members, little change can take place in the classroom. The leadership required to encourage local deployment, spur courseware development, help teachers build new skills, and secure budget funds, grants, donations, and subsidies, will need to come from both the public and private sectors. To some extent, this process has already begun, and leaders are emerging. But without broader intervention, the process will likely be slow and inequitable. While no single blueprint for deployment can meet the diverse needs of every school district, it is equally true that individual schools will need help in marshaling resources and moving forward.

Strong leadership has been a key success factor in every case study we examined. Local leaders at innovative schools like the Ralph Bunche School in New York City, the Carrollton City School District in Georgia, and the schools in California's Hueneme District have pioneered the way, and students in those schools are already profiting from the educational benefits of technology. Actively encouraging experiments and initiatives in many more schools and districts around the country could result in widespread and significant improvements in American education.

INTRODUCTION

Giving the nation's public K-12 schools access to the national information infrastructure (NII)—or "information superhighway"—over the next 5 to 10 years could produce significant educational benefits. But, realistically, what would it take to accomplish this? Would it be technically feasible in that timeframe? How much would it cost? Where would the major challenges arise?
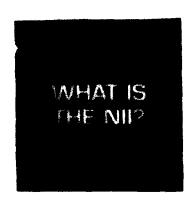
At McKinsey & Company, Inc., we developed a fact base and perspectives to help policymakers and educators address these and related questions.* This report, which was prepared as a submission of information to the National Information Infrastructure Advisory Council (NIIAC), summarizes our analysis of options for connecting the nation's public K-12 schools to the information superhighway. The report incorporates insights on connecting to the NII drawn from visits to schools and interviews with educators, policymakers, and technology experts around the country, as well as from a review of the available literature on the educational uses of technology and connectivity.

The report begins with a summary of the principal applications and benefits of connecting public K-12 schools to the NII. (See also the sidebar "What Is the NII?" which briefly describes the key elements that make up the information superhighway.) Then, to illustrate the costs and highlight the challenges of capturing those benefits, the report describes a series of models for deploying the required technology infrastructure—that is, for putting into place the needed connections,

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hardware, content, and human resources. The next section identifies the three major challenges to successful deployment—funding, professional development for teachers, and courseware development—and outlines a number of potential ways to clear those hurdles. The report concludes by highlighting some of the leadership challenges posed by technology deployment, underscoring that success will ultimately depend on the creativity and sustained commitment of leadership at all levels—school, district, community, state, and national.

This report does not attempt to lay out a national blueprint for infrastructure deployment, nor does it recommend specific public policy goals. Each school or district has its own unique needs, opportunities, and challenges; no one blueprint could possibly address them all. Accordingly, successfully deploying the infrastructure will require an approach flexible enough not just to allow individual schools to set their own pace and priorities, but actively to encourage local experimentation and innovation. In addition, this report does not evaluate the relative merits of competing demands on educational funding (e.g., more computers versus smaller class sizes). We recognize that educators and policymakers will have some difficult choices to make in determining the appropriate budgetary priorities and tradeoffs. To assist such deliberations, this report provides an economic analysis of various options for connecting schools to the NII. We hope that this analysis will inform the public debate on actions to take at the school and district level as well as provide a useful fact base for analyses and recommendations developed by the NIIAC.

WHAT IS THE NII?

Across the country, students in a number of schools are already connecting to the national information infrastructure (NII), also called the "information superhighway," and tapping into an array of resources that can help them build valuable information, computer, and networking skills.

The NII is composed of electronic networks

The NII is a collection of electronic networks providing access to applications—programs, services, and communications—via computers, telephones, and video equipment. It comprises thousands of local area and wide area networks. Local area networks connect computers, printers, and other equipment in one room or building. Examples of local area networks include the electronic linkages among desktop computers present in most business offices and school computer labs, or the connections between the computers at the local Department of Motor Vehicles office. Wide area networks link devices in multiple or distant locations, like the public telephone system that transmits telephone calls or the cable television system that distributes programming throughout a city. The Internet, which many people use to link computers together, is yet another wide area network and one that is employed by many schools. Wide and local area networks can transmit information using telephone lines, cellular networks, satellite links, cable systems, or some combination of these.

A network typically increases in value as more users gain access to it. The public telephone network is valuable because almost everyone has a telephone and uses the network. Likewise, fax machines quickly became required business tools once enough machines were in use. The same is becoming true of computer networks. Electronic mail addresses, once the province of computer nerds and academics, are now becoming common.

Networks deliver applications

A growing range of applications are available through the NII. On-line services like America On-Line, Prodigy, and Compuserve (which include wide area networks) allow users from around the globe to access many types of information, like stock market quotes or entertainment listings, and to electronically purchase services, like floral deliveries or research requests. Communities such as Charlotte, North Carolina, have networked the public library and government offices to provide residents with access to job listings and announcements of community events. Video and telephone conferences are available through the NII from a variety of service providers. These applications and services will keep expanding as technology evolves and on-line activity grows.

Many educational applications can be found on the information superhighway. For example, National Geographic's Kids Network allows students from around the country to participate jointly in science experiments on-line. Channel One delivers education-focused news programming to thousands of schools each morning through its satellite system. Cable in the Classroom, a consortium of cable operating companies, delivers over 500 hours of educational programming each month. Students in rural parts of the Guilford County, North Carolina, school district are now able to take pre-college physics—from a teacher at another, larger high

school—by using the district's new distance learning facilities and connection to the North Carolina Information Highway. Administrators in a California school district use a videoconferencing system that operates over the local cable television network to discuss best practices and new policies; these conversations rarely took place before. In a number of districts, students, teachers, administrators, and parents are discovering the increased communications made possible by electronic mail. Similar to the broader business and consumer uses of the NII, the quality and quantity of available educational services will expand as the NII develops.

The foregoing describes a little of what a school can do with network access. But not all educational applications are being delivered over networks today. In fact, many high-quality educational applications are available in "stand-alone" format. A host of course materials are available on videotape and laserdiscs. Skill-building CD-ROM simulation programs and other software for computers account for the vast majority of electronic content sold today to the schools. The line between stand-alone and networked applications is not always clear, however. As networks develop, many applications available only in stand-alone form may be delivered more cheaply and conveniently over networks in the future.

Different applications require different bandwidths

The services accessible by any given user depend on the platform (computer, video or voice) and bandwidth available to the user (see Exhibit 1: "Applications Landscape"). Bandwidth refers to the amount of information that can be transmitted over a network within a given time. Just as only so much water can flow through a 12" drain pipe, networks also have capacity limitations. These limitations are typically measured by the number of pieces of digital information, or "bits," that can be transmitted per second. Typical telephone lines (called POTS lines) are technically capable of moving up to 34 thousand bits per second (kbps), though 14.4 kbps connections are most common today. To the average student connected to the Internet via a telephone line, this means waiting 30 seconds or more for one full-color computer screen of information. However, faster telephone services are becoming more widely available. ISDN ("Integrated Services Digital Network") lines provide for speeds starting at 56 kbps, which significantly reduces the time required to receive one screen of information. And some schools are accessing networks through high-speed T-1 telephone lines, which operate at over 1.5 million bits per second (mbps) and allow 24 students fast, concurrent access to networks.

There are certain applications that require even more bandwidth, like the amount available through fiber optic or coaxial cable. These new services make extensive use of audio and video, and include video-on-demand, desktop videoconferencing and whiteboarding, virtual field trips via video networks, and networked simulations. At least one company, The Lightspan Partnership, plans to use high-speed broadband networks and video equipment to transmit interactive curricular materials into both classrooms and homes. While most of the educational applications available today do not require fast, high-capacity broadband connections, greater bandwidth would enhance the quality and speed of existing applications, as well as encourage developers to take advantage of the new capabilities.
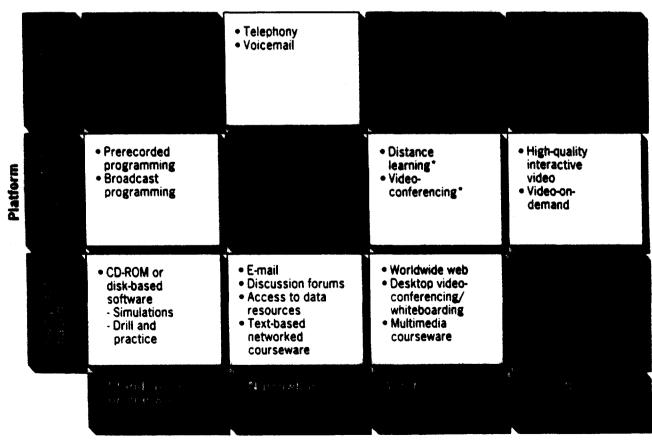
WHAT IS THE NII?

Bandwidth availability is growing

How fast can the average school expect to gain access to broadband networks? Although the answer is quite uncertain, it seems likely that broadband will not be widely available until sometime in the early 21st century. The answer depends on a number of developments in the regulation of telecommunications companies, the state of competition between those providers, and market demand for enhanced services requiring broadband technology. Some states—including North Carolina, Iowa, and Hawaii—have taken steps to accelerate the deployment of broadband networks in the public realm. Schools in these states have access to such networks today, though some find the price high relative to other technology items. Other states, including Kentucky, are currently in the process of designing their broadband networks. While such efforts are important, schools can get started on connecting to the information superhighway now, even if they do not have broadband access yet.

Exhibit 1

APPLICATION LANDSCAPE EXAMPLES

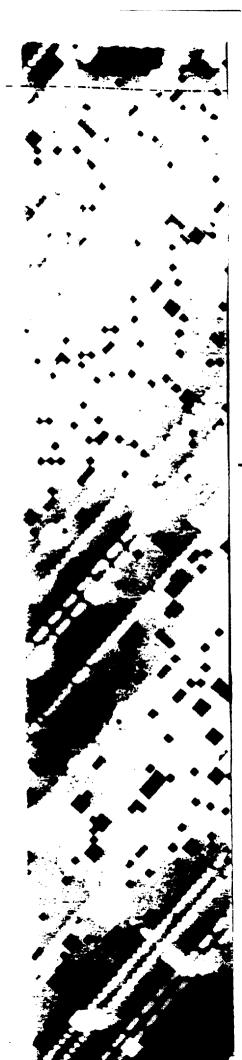|			
	• Telephony • Voicemail		
• Prerecorded programming • Broadcast programming		• Distance learning* • Video-conferencing*	• High-quality interactive video • Video-on-demand
• CD-ROM or disk-based software - Simulations - Drill and practice	• E-mail • Discussion forums • Access to data resources • Text-based networked courseware	• Worldwide web • Desktop video-conferencing/ whiteboarding • Multimedia courseware	

Platform (vertical axis)

Bandwidth **

* Business quality with ISDN; professional quality with TI (assuming existing compression technology)

** Required bandwidth also depends on number of concurrent users

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BENEFITS OF CONNECTING TO THE NII

Connecting public K-12 schools to the NII could produce a variety of educational benefits. Clearly, it would enable students to build computer and networking skills. Early evidence indicates that it could also support both traditional teaching approaches and new methods oriented toward teaching problem solving and critical thinking skills. Certainly, students find the technology exciting and engaging, it provides them access to a wide range of information resources, and it opens up communication with subject-matter experts, other students, and teachers.

Providing students with access to networked computers helps prepare them for the economy and society they will face in the 21st century. Basic competence in the use of computers and electronic networks is becoming a fundamental requirement for employment in the better jobs in the U.S. economy. According to research conducted by the Children's Partnership, 47% of jobs in 1993 required computer and/or networking capability—up from 25% in 1984.[1] By the year 2000, this study forecasts, 60% of jobs will require these skills and will reward them with a 10-15% pay premium over jobs that do not require such capabilities. In addition, the growing availability of on-line information and research resources gives a competitive advantage to students and workers who can effectively use these tools in their studies or jobs.

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[1] *America's Children and the Information Superhighway* (Washington. D.C.: September 1994).

These facts alone convince many educators and policymakers that connecting schools to the NII, and thus giving public school students exposure to computers and networking, is important. In addition, demonstrating that computers and connection to the NII can make a fundamental difference to students' achievement in academic subjects would persuade a broader constituency about the importance of deploying this technology in the schools.

To date, the evidence is strongest concerning the use of stand-alone computers in teaching. Currently, stand-alone computer applications are both the most widespread[2] and well-researched use of technology in classrooms. *The Effectiveness of Technology in Schools, 1990-1994*, presents a comprehensive review of over 130 recent academic studies.[3] The review found that using technology to support instruction can improve student outcomes in a wide range of subjects, including language arts, math, social studies, and science. In a study of writing skills, for example, researchers found that the papers of eighth graders using word processors were consistently superior to handwritten papers in mechanics, organization, and focus.[4] In another study, third and fifth grade math students received either computer-assisted instruction (CAI) or traditional classroom instruction for 71 days. The students who received CAI demonstrated gains, measured in months of grade placement, about twice that of the students receiving traditional instruction.[5] Since the study was controlled for time on task, the results were largely attributed to the effectiveness of CAI. Even more striking, the study quantified the cost of gaining a month of grade placement by various methods, and concluded that CAI was a more cost-effective approach to raising mathematics scores than tutoring, increased instruction time, or reduced class size.[6]

The use of computers seems to have even greater effects with low achieving and remedial students. A review of New York City's Computer Pilot Program, focused on educationally disadvantaged students, found that participating students achieved gains of 80% for reading and 90% for math.[7] In a review of 20 studies of the effect of word processing on writing quality, researchers found a 27% improvement

[2] See University of California, Irvine, Department of Education, *Analysis and Trends of School Use of New Information Technologies* (U.S. Department of Commerce, National Technical Information Service, 1994), pp. 30-44.

[3] Ellen R. Bialo and Jay Sivin-Kachala, *Effectiveness of Technology in Schools, 1990-1994* (Washington, D.C.: Software Publishers Association, 1995).

[4] Ronald D. Owston, Sharon Murphy, and Herbert H. Wideman, "Effects of Word Processing on Student Writing in a High Computer Access Environment" (North York, Ontario: York University Centre for the Study of Computers in Education, June 1991); discussed in *Effectiveness of Technology*, supra note 3.

[5] J.D. Fletcher, D.E. Hawley, and P. K. Piele, "Costs, Effects, and Utility of Microcomputer Assisted Instruction in the Classroom," *American Educational Research Journal*, vol. 27, no. 4 (Winter 1990), pp. 783-806. Students in the third grade demonstrated relative gains of 5.70 months for CAI versus 2.86 months for traditional instruction; for the fifth grade students, the gains were 8.89 versus 4.94 months.

[6] Ibid., pp. 800-802.

F. Guerrero, M. Mitrani, J. Schoener and Swan, "Honing in on the Target: Who Among the Educationally Disadvantaged Benefits Most from What CBI?," *Journal of Research on Computing*

overall but a 49% improvement where remedial students were involved.[8]

A few reports have attempted to quantify the pattern of results emerging from the hundreds of individual studies. In a review of 254 controlled studies. researchers found that CAI helped students to learn 30 percent faster than students receiving traditional instruction.[9] The implication of this 30 percent gain is that students receiving CAI would gain a year relative to their peers for every three in school.

Many schools and districts have used CAI and other technology as part of their strategies to boost achievement. For example. the Carrollton City School District in Georgia implemented a computer lab. among other changes, to reduce the failure rate in 9th grade algebra from 38% to 3%. Students at the Clearview Elementary School. in Chula Vista. California. typically scored in the bottom 10% on standardized achievement tests until the school underwent restructuring, including the deployment of advanced technology. Within 2 1/2 years, test scores reached the 80th percentile.[10] The Christopher Columbus Middle School went from performing well below New Jersey state averages on standardized tests to above average in reading. language arts, and math within a few years of implementing reforms including extensive use of networked computers at school and home.[11]

The method by which stand-alone computer technology appears to deliver these benefits differs by subject. Student writing skills seem to improve because computers enable students to write two to three times as many words in the same amount of time and make rewriting much easier.[12] For subjects like mathematics, where symbolic logic plays an important role, computer applications allow students to visualize the concepts they are studying.[13] Computers also permit a greater degree of individualization in instruction: interactive software paces

in Education (Summer 1990), pp. 381-403; discussed in *Effectiveness of Technology in Schools*, supra note 3. p. 9.

[8] Bangert-Drowns. "The Word Processor as an Instructional Tool: A Meta-analysis of Word Processing in Writing Instruction." *Review of Educational Research*. 63 (1), 1993, pp. 69-93; discussed in *Effectiveness of Technology in Schools*, supra note 3. p. 3.

[9] Chen-Li Kulik and James A. Kulik. "Effectiveness of Computer Based Instruction: An Updated Analysis." *Computers in Human Behavior*. 7 (1991). pp. 75-94. The technique used by the researchers is termed meta-analysis: it provides a method for normalizing results across studies employing different measurement approaches. To further put the results in perspective. 94% of the statistically significant cases reviewed favored CAI. See also A.W. Ryan. "Meta-Analysis of Achievement Effects of Microcomputer Applications in Elementary Schools." *Educational Administration Quarterly*. 27 (1991). pp. 161-184 (meta-analysis of 40 studies focused on elementary school children that also found 30% gains in learning). Another meta-analysis found an achievement effect of 50% from videodisc- and videotape-assisted instruction based on a review of 63 studies: see Barbara J. McNeil and Karyn R. Nelson. "Meta-Analysis of Interactive Video Instruction: A Ten-Year Review of Achievement Effects." *Journal of Computer-Based Instruction* (Winter 1991). pp. 1-6.

[10] Interview with Carol Welsh. Program Manager. 21st Century Education Initiative. Joint Venture Silicon Valley Network. September 1995.

[11] "The Haves and the Have-Nots." *Newsweek* (February 27. 1995). p. 50.

[12] Given at least 15 minutes of practice a day, third graders learned to type 20-30 words per minute with 95% accuracy over a six-week period. Third grade children typically write nine to eleven words per minute by hand. David Dwyer. "Apple Classrooms of Tomorrow: What We've Learned." *Educational Leadership* (April 1994). pp. +10.

[13] M.P. Alexander. "The Effective Use of Computers and Graphing Calculators in College Algebra."

exercises at a tempo and difficulty level appropriate for the individual student. and provides immediate feedback and reinforcement.[14]

Networking and networked applications can support the use of CAI by making software more easily available to students: by providing wider access to skilled teachers, experts, and resources: and by creating opportunities for collaboration that make learning activities more engaging. For example, students using electronic mail have demonstrated significant increases in reading and writing skills.[15] In a controlled distance learning experiment, students at seven high schools received anatomy and physiology instruction via satellite, with a local science teacher facilitator, while students at another seven high schools received face to face instruction. The students receiving distance learning achieved "at a significantly higher level" than their peers. The difference may have been in the skills of the distance learning teacher.[16]

Today, many educators are focusing increasing attention on a cross-disciplinary teaching approach that emphasizes critical thinking, synthesis, and investigative skills. Based on interviews and visits to schools, we believe that connection to the NII and widespread use of computers have the potential to support this new approach. On-line resources give students rapid access to information from diverse sources in various forms. Thus, the challenge of finding the facts can quickly give way to the challenge of synthesizing and interpreting the facts. Simulation software develops problem-solving skills by allowing students to tackle life-like challenges and experiment with different solutions in real time. For example, the Dalton School's "Archaeotype" program places students in the role of archaeologists on a dig. They work in teams to access and analyze multiple sources of electronic, printed, and human information. Networking the computers further facilitates team-based projects in and across classrooms, building skills that many educators and employers believe are important for students' development.

Admittedly, the research literature is thinner with respect to technology's contribution to building critical thinking and synthesis skills.[17] Though researchers point to improved student ability to solve multi-step word problems,[18] or even 50% overall improvement in critical thinking ability,[19] the exact sources of these improvements are still difficult to isolate. But looking at what actually goes on in the classrooms of inno-

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Dissertation Abstracts International, 54/06-A, 1993; discussed in *Effectiveness of Technology in Schools*, supra note 3, p. 32.

[14] See F. Guerrero, et al., supra note 7.

[15] See for example Patrick O. Rooney, *The Report of the Evaluation of the Model Technology School Program in the Hueneme School District* (Hueneme School District Board of Education, 1992).

[16] E.D. Martin and L. Rainey, "Student Achievement and Attitude in a Satellite-Delivered High School Science Course," *The American Journal of Distance Education*, 7(1), pp. 54-61.

[17] In part this is true because achieving benefits of this type requires many pedagogical changes, making it difficult to isolate the impact of technology per se. It is also true that longitudinal studies are needed to measure differences in student achievement over time; few if any such studies have yet been completed simply because connectivity in the schools is a very recent phenomenon.

[18] Cognition and Technology Group at Vanderbilt University, "The Jasper Series: A Generative

vative schools makes these improvement figures seem reasonable. A visit to the Hueneme School District in California illustrates this point. As explained in the side bar ("Case Study—Hueneme"), this school district has, over the last 12 years, changed most aspects of its educational approach. New classroom layouts, new curricula, involvement of parents in the education process, and teacher-led innovation in instruction have all contributed to a dramatic increase in academic performance. Students seem highly engaged in the learning process, and teachers relish their new roles as coaches rather than lecturers.

Such vigorous and creative integration of technology into daily classroom teaching can bring about fundamental changes in the way schools carry out their educational mission. But it requires more investment in hardware, courseware, and professional development for teachers than would be necessary just to teach basic technology skills or support stand-alone computer applications. It requires more time to implement. And it requires the courage to be a pioneer: best practices for integrating technology into the classroom are still being discovered—they have not yet been meticulously researched and measured. However, pioneering schools like those in the Hueneme District have shown that students can benefit substantially from careful integration of technology into the classroom, supported by well-trained teachers.

Even when deployment is much less sweeping and sophisticated, connectivity still brings new resources to schools. Specialized teachers, subject matter experts, remote libraries and databases, and virtual field trips enrich the educational experience of students connected to the information superhighway. Distance learning, in which students participate in courses offered at other locations via video technology, can be especially useful for rural or inner city schools with limited resources. This interactive video technology enables these schools to expand their menu of courses and supplement their roster of teachers.

Connectivity further enriches the learning environment by providing new channels of communication. For example, electronic mail facilitates communication among students and their teachers, administrators and parents. Many students raise issues and ask questions through electronic mail that they would be reluctant to pose to an adult face-to-face. The Internet and other on-line services also allow students to communicate with a wide variety of professionals and other students around the world, broadening the educational community.

It seems clear that the impact on student motivation levels is significant. The Christopher Columbus School, which extensively uses networked computers, has its district's best attendance record for both students and faculty.[20] In the Carrollton District, the dropout rate declined from 19% to 5% after deployment of technology.[21]

Approach to Improving Mathematical Thinking," *This Year in School Science* (Washington, D.C.: American Association for Advancement of Science, 1991).

[19] Rooney, supra note 15.

Twelve years ago, students in the Hueneme School District scored right around the average in math, reading, science, and history compared to students in similar schools and districts in the state of California. Today, average student test scores in this K-8 district near Santa Barbara have risen to above the eightieth percentile. Perhaps even more impressive, academic researchers using the Cornell Critical Thinking Test have found that students' average critical thinking abilities have risen from the fortieth percentile to the eightieth percentile when measured against their peers.

Pinpointing the source of these dramatic improvements is difficult. But the teachers and parents in the Hueneme district attribute the difference in large measure to the fact that the last twelve years have been marked by a substantial investment in educational technology, including computers, networking, and teacher training. Today, the Hueneme district has one of the most advanced technology infrastructures in the nation, as well as a carefully crafted program for integrating technology into subjects as varied as science and history.

With nearly one computer per student distributed across classrooms and libraries, and video equipment in every room, Hueneme schools are well equipped on the technology front. But the teachers and the administrators have gone another important step by literally redesigning the physical layout of their classrooms to make optimum use of the technology and maximize teacher-student interactions. In Hueneme's "smart classrooms" students no longer sit in rows behind desks and listen passively to lectures. Instead, computers and video monitors have been integrated into "learning pods" in which students work together, facing each other.

This dynamic learning environment is supported by a number of networks that link schools in the district to each other and to the Internet and other national networks. All 11 schools, the district office and maintenance facilities have local area networks that are connected to the Hueneme Wide Area Network (HWAN) which, in turn, is linked to the Internet. Cable linkages, provided by the local cable company, Jones Intercable, Inc., connect all district classrooms to enable video-conferencing across the district. And one school, Blackstock Junior High School— a state of California Model Technology school site—has an advanced fiber optic local area school network, which will be replicated in other district schools within the next 12 months. This junior high is also connected to a national wide area network that includes several schools from other states and the MCI laboratory in Richardson, Texas.

For Hueneme students, technology and connectivity provide an exciting learning environment in which they can master educational basics while learning skills that prepare them for the future. At Blackstock Junior High, for example, each day begins with a live, school-wide video broadcast of the day's events that is scripted, produced, recorded, and transmitted over the internal video network by the students. With the touch of a button, students in a social studies class bring geography to life with digitized terrain maps, recordings of national anthems, and video clips of life and culture in other nations. Science students can watch and interact with computerized physics experiments—such as simulated stress testing of student-designed surfaces—that would be otherwise virtually impossible to carry out. A direct connection to the Lawrence Livermore Lab's Cray super-computers allows students to review alternative strategies for solving complex math and science projects.

The dramatically changed learning environments in Hueneme did not appear overnight. Rather, they are the product of years of experimentation. The district started 12 years ago with one computer lab in a single school. Classroom use of computers began when one teacher agreed to spend a semester designing a science classroom with individual computer stations set up to teach different science concepts; the smart classroom was born. Since then, teachers have designed rooms for other subjects ranging from math to English to social studies and have utilized time away from instruction to design new curricula that take advantage of the new learning environments. In 1995, the twelfth-generation smart classroom design of learning pods and videoconferencing capability was unveiled for student use.

None of the benefits engendered by technology and connectivity in the Hueneme district would have been possible without the combined support of the district administration, school board, teachers, parents, and community leaders. The district superintendent, Dr. Ron Rescigno, has provided vision, leadership, and moral support to the critical agents of change, the teachers. "We have a clear focus on technology," he says. "The key is to keep experimenting—pushing the envelope—and then integrate what you learn into the next deployment of technology. Teachers here know they are taking risks when they use educational technology, but they know they have the support of the district. I don't think we are anywhere near to having perfected classroom use of technology. I don't know if we will ever perfect it. There will always be new developments to consider."

Connecting schools to the information superhighway also helps teachers and others to better help students; in fact, connectivity can provide benefits for a wide range of stakeholders (see Exhibit 2: "Benefits to Education Stakeholders"). Importantly, network technology frees teachers from the isolation of the classroom. Communicating easily with other educators is a significant benefit for teachers who spend most of their time in the classroom and, consequently, have traditionally had little contact with other professionals with whom they could share experiences and ask questions. By contrast, today there are dozens of education-focused discussion groups on the Internet, addressing a wide range of topics from best practices in distance learning to reviews of new software and textbooks. For example, a science teacher we met in the Hueneme School District is constantly sharing his experiences using his school's new educational technology with other teachers through the Internet. Connecting to the NII helps teachers such as this one form a learning community that can advance a variety of educational goals.

Voice mail, electronic mail, and administrative applications (e.g., attendance-taking, grade record-keeping) can also improve communications among teachers, as well as parents and administrators. At the Math and Science Technology magnet school in Los Angeles, California, Greta Pruitt, the principal, told us: "E-mail allows teachers to pose questions to each other and to me when they have the time. On the system, we can respond to each other at our convenience and we avoid the 'let's talk later' syndrome that is part of working with children."

Parents also benefit through increased connection with their children's learning process. Linking parents to the school network—through home computers or through after-hours sessions at a school, library, or community center—can involve them directly in their children's education (e.g., by allowing them to follow along with homework assignments or to correspond more easily with teachers). At the Dalton School in New York, for instance, parents use electronic mail extensively to discuss classes and the performance of their children. Parents and children at the Union City school in New Jersey make use of the lab after-hours to work jointly on assignments.

While this report focuses primarily on the benefits the NII can bring to schoolchildren, the necessary infrastructure, once deployed, can clearly benefit other constituencies as well. Once in the school, computers and networks can provide wide access to services provided by the information superhighway. The Ralph Bunche School in New York offers use of its computers to parents, who come in after hours
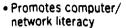
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[20] U.S. Department of Education. *Telecomputing for Teaching and Learning: Stories of People Using Computer Networking for Learning* (November 1994), p. 9.

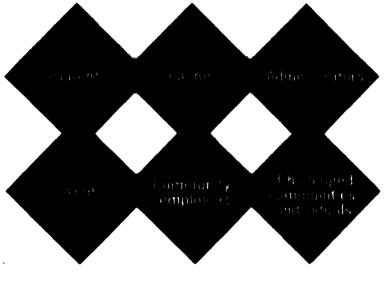[21] For more information, see "Case Study: Carrollton School District, Georgia," infra p. 39.

Exhibit 2

BENEFITS TO EDUCATION STAKEHOLDERS

• Enables greater individualized attention
  to students
• Promotes communications with other teachers,
  school professionals, and outside experts
• Enhances productivity

• Promotes computer/
  network literacy
• Increases motivation
  to learn
• Increases learning/
  achievement
• Provides access
  to more resources
• Promotes communi-
  cations with others

• Increases record-keeping
  efficiency
• Promotes communications
  with other professionals
  and teachers

• Increases access to
  student information
• Promotes
  involvement in
  children's education
• Promotes life-long
  learning

• Levels playing field by
  ensuring access
• Provides opportunity to
  be information producers
  and preserve culture

• Increases skills of work force
• Promotes community interaction

to develop computer and network literacy and accelerate their learning of English. In fact, activities such as these could potentially bring in revenue to help defray the cost of building technology infrastructure in schools.

It follows that as more schools network with each other, the possibilities for sharing learning multiply. The same principle applies to connecting schools with homes, local libraries, and community centers involved in promoting lifelong learning. Indeed, some communities in Tennessee, New Mexico, and elsewhere are now experimenting with community-wide networks that link up schools, libraries, community centers, and other organizations to provide a wide range of educational and social benefits for diverse groups of local stakeholders (see sidebar on "Libraries, Community Centers, and Community Networks.")

LIBRARIES, COMMUNITY CENTERS, AND COMMUNITY NETWORKS

Schools are not the only community institutions that can provide NII-based services. Libraries and community centers are likely to be an important piece of the NII equation for most communities. These institutions can help educate children, support lifelong learning, provide public access to the information superhighway, and allow consumers of information to become producers of information in much the same way schools can.

Public libraries. Already responsible for providing information access and education programs, public libraries are well positioned to provide access to the NII. The specific infrastructure any given library would want to build is a function of its resources and the emphasis the community places on the many possible roles a public library could play.

Libraries currently support children's education through a range of reading, storytelling, tutoring and other programs; as places to do homework; and as information providers for student research. As many libraries have already discovered, computers and networks can add significantly to the library's tools. For example, the public library in Arlington, Virginia, recently acquired a multimedia computer along with educational and "edutainment" software; computer time is always in high demand. The award-winning Charlotte, North Carolina, public library has established three satellite centers with computer and network access to serve at-risk youth in their communities on weekends and after school.

Many state, county, and city library systems have launched programs to provide patrons with access to community and subject-oriented information specifically and to the information superhighway generally. The State of Maryland, Allegheny County in Pennsylvania, and the City of Seattle are among those who have initiated such efforts. For example, Maryland's *Sailor*, the state's on-line public information network, is currently available through hundreds of public library terminals. In addition to Internet access, *Sailor* provides information on city, county, and state government; libraries and education resources; and subject-oriented information on science and technology, entertainment and leisure, employment, and other topics.

In Allegheny County, Pennsylvania, the Electronic Information Network (EIN), a partnership between the Carnegie Library of Pittsburgh and the county library community, seeks to link Allegheny County's public libraries to each other and the information superhighway. As part of the EIN, Carnegie Public Library is also the headquarters and sponsor of the Three Rivers Free-Net. The Free-Net will provide access to the Internet as well as a place for community organizations to publish public service information. Information mounted on the Free-Net will include information on social service agencies, calendars of events, weather news, local government information, city guides, and consumer information.

Seattle Public Library's citywide network allows access to the Internet and local information resources through 200 public-use terminals in 20 neighborhoods and 2 housing projects. Dial-in and telnet connections are also available.